ECWS

MDPI

Spatio-Temporal Dynamics of Dished Lake in Poyang Lake and Its Ecological Effects

Hai Liu [1], Shimian Wang [1], Zeyu An [1], Min Wang [1,*] and Liang Zheng [2,*]

[1] Faculty of resources and environment Science, Hubei University, Wuhan 430062, China
[2] State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, Wuhan 430079, China
* Correspondence: 45541829@qq.com (M.W.); 1241580102@qq.com (L.Z.)

Abstract: The dish-shaped lakes are seasonal sub-lake exposed on the beach during the dry season of Poyang Lake. Its special hydrological and geomorphic characteristics provide a good habitat for more than 80% of the lake's wintering migratory birds. On the other hand, the widely distributed dish-shaped lakes with varying heights effectively alleviated the impact of drought and flood disasters on the Poyang Lake wetland ecosystem, and are of great significance to maintaining the stability of the Poyang Lake basin ecosystem and biodiversity. This study takes Poyang Lake's dish-shaped lake as the research object, based on long time series remote sensing data, it analyzes the temporal and spatial dynamic characteristics of water area from different time scales (month, quarter, and year); combined with naturel and human factors analysis of the driving factors of its changes. On this basis, the ecological effects brought by the dynamic changes of the dish-shaped lake water area were discussed from the aspects of wetland vegetation and migratory bird habitat changes, in order to lay a foundation for the protection of wintering migratory birds and their habitats in the region, and to maintain the Poyang Lake ecosystem provide guidance on safety and biodiversity.

Keywords: saucer lake; NDWI; long time sequence; SPATIOTEMPORAL variation; ecological impact

PACS: J0101

1. Introduction

The dish-shaped lake is a shallow dished depression formed in the process of uneven deposition due to the interaction of current and sediment in the estuary Delta [1]. Poyang Lake is aunique huff and puff type seasonal lake, with the hydrological characteristics of "high water is a lake, low water is like a river", and the water area of the year has significant difference [2]. The dish shaped lakes of Poyang Lake are densely distributed around the lake basin, and the total area accounts for 22.25% of the total area of Poyang Lake [3]. This area is also the location of Poyang Lake National Nature Reserve [4]. With the change of water area in the lake area, the saucer lake appears seasonally: in the wet season, the saucer lake is connected with the main lake area; in the dry season, the saucer lake is separated from the main lake. Dish shaped lakes vary in size and shape, surrounded by artificial high lake levees separated from the river water area [5]. The hydrological and geological processes are affected not only by the main lake area, but also by the rivers entering the lake, creating complex and diverse freshwater biological communities, and also reflecting the historical process of hydrological situation and geomorphic evolution to a certain extent.

According to the results of basic geographic survey of Poyang Lake organized by Jiangxi provincial Party committee, a total of 77 dish-shaped lakes were selected (as shown in Figure 1). Most of the study area is located in the water land transition zone, belonging to the wetland ecosystem. It is the Poyang Lake drought and flood buffer zone and the main activity area of fish spawning and migratory birds [6-7]. Strengthening the monitoring and Research on the dynamic changes of water

area in the dish-shaped Lakearea. It plays an important role in maintaining wetland ecology and species diversity in Poyang Lake area.

Figure 1. The Lake saucer is in the Poyang Lake Range.

At present, some scholars have carried out a lot of research on the dynamic changes of water resources in Poyang Lake [8-14], but there is no long-term monitoring results for the dish-shaped Lake area [15]. Due to natural factors such as climate change and frequent human activities, the dish-shaped lake has become the most affected area of Poyang Lake [16-17]. Based on the remote sensing image data, this paper realizes the monitoring of water area change in the saucer Lake region in a long time sequence, analyzes the spatial-temporal change trend of the dish-shaped Lake area and the relationship with the main lake area, and then studies and analyzes the driving factors of the change, so as to provide the basic data support for the influence of the saucer Lake area on the nature and society as an important wetland resource and biological resource.

2. Materials and Methods

2.1. Data introduction

In this paper, 278 Landsat TM/ETM+/OLI images and 237 HJ-1A/B images were collected from geospatial data cloud platform (http://www.gscloud.cn/)and China Resource Satellite Application Center(http://www.cresda.com/site1/), with a total of 515 images.

Table 2. Monthly available data.

Month	1	2	3	4	5	6	7	8	9	10	11	12
Earliest year	1990	1989	1989	1976	1981	1978	1977	1977	1978	1975	1983	1973
Latest year	2018	2018	2016	2018	2017	2018	2018	2017	2017	2018	2018	2017
Number of images	28	30	29	46	39	27	58	53	49	69	54	52

The precipitation and evaporation data of stations near Poyang Lake from 1973 to 2018 were obtained from China National Meteorological Information Center（http://data.cma.cn/）. The rainfall data is from the monthly value data set of China surface climate data, a total of 4416 pieces; the evaporation data is from the monthly value data set of China International Exchange Station surface climate standard value, a total of 48 pieces. The average monthly precipitation and evaporation of Poyang Lake area were counted, and the water surplus and deficit were calculated.

2.2. Method

For the extraction of water information, in order to ensure the comparability of data time scale and water extraction results of various data, the normalized difference water body index (NDWI) method is adopted in this paper. Its advantage is that the extraction effect of shallow water area and small water area is good. Through the combination of green band and infrared band, the influence of vegetation, terrain and mountain shadow can be greatly suppressed It is applicable to the study 23 area [24].

Specific formula [25]:

$$NDWI = (Green - NIR)/(Green + NIR)$$

Among them, "Green" represents green light band, "NIR" represents near red band, which are band 2 and band 4 of Landsat and HJ series satellites respectively.

After the establishment of the model, combined with visual interpretation to set the appropriate threshold to extract the water(different sensors have different thresholds for simultaneous interpreting). According to the monthly and interannual summary to calculate the each year and month's the average, minimum and maximum value of water area in saucer Lake,and then obtain annual and monthly variation characteristics of the area.

3. Results

3.1. Changes in Water Area

3.1.1. Monthly Variation

Table 1. Lunar surface area of dish-shaped lake (km²).

Month	1	2	3	4	5	6	7	8	9	10	11	12
Mean	173.67	199.65	232.62	323.72	387.54	536.99	640.67	570.71	548.66	378.37	257.21	170.05
Min	145.30	131.75	147.12	154.43	192.90	226.12	277.79	280.26	230.35	158.91	154.96	125.29
max	233.76	311.53	344.12	704.51	678.84	734.52	753.70	751.53	752.85	746.16	581.85	275.90
fluctuation	88.46	179.78	197	550.08	485.94	508.4	475.91	471.27	522.5	587.25	426.89	150.61

It can be seen from table 1 that during the whole study period, the monthly average water area of saucer Lake area fluctuated between 170 km² ~ 640km², the maximum values were all more than 200 km², and the minimum values were all lower than 300 km². The water area fluctuation in October was the largest with significant difference. At this time, it was in the period of "cutting the lake", which was mainly influenced by human factors of releasing water for fishing. The average water area of the saucer lake is 383.30 km².

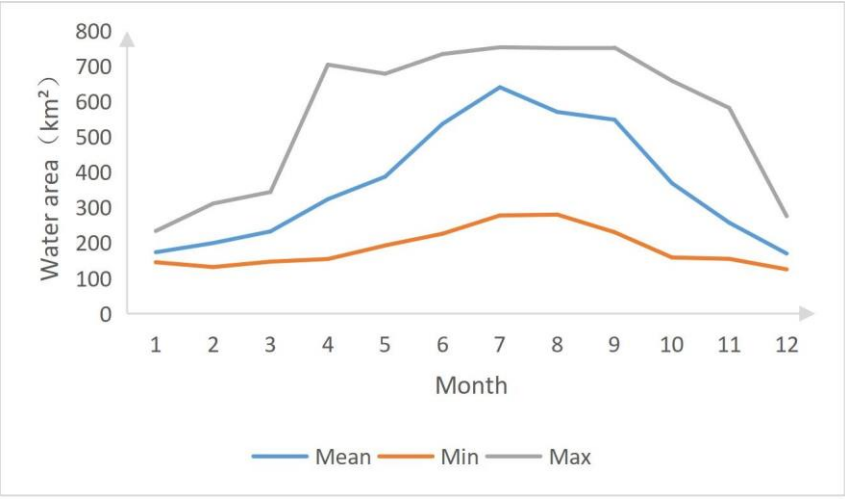

Figure 2. Lunar surface area curve of dish-shaped area.

It can be seen from Figure 2 that even in the same month, the difference in water area of saucer Lake area is more significant. On the whole, the monthly average water area of saucer Lake showed a unimodal change in the year, with an upward trend from January to July, reaching the maximum value in July, and then showing a downward trend, reaching the minimum value in December.

3.1.2. Interannual change

The annual average water area of Saucer Lake area is calculated by monthly water area of each year (Figure 3).

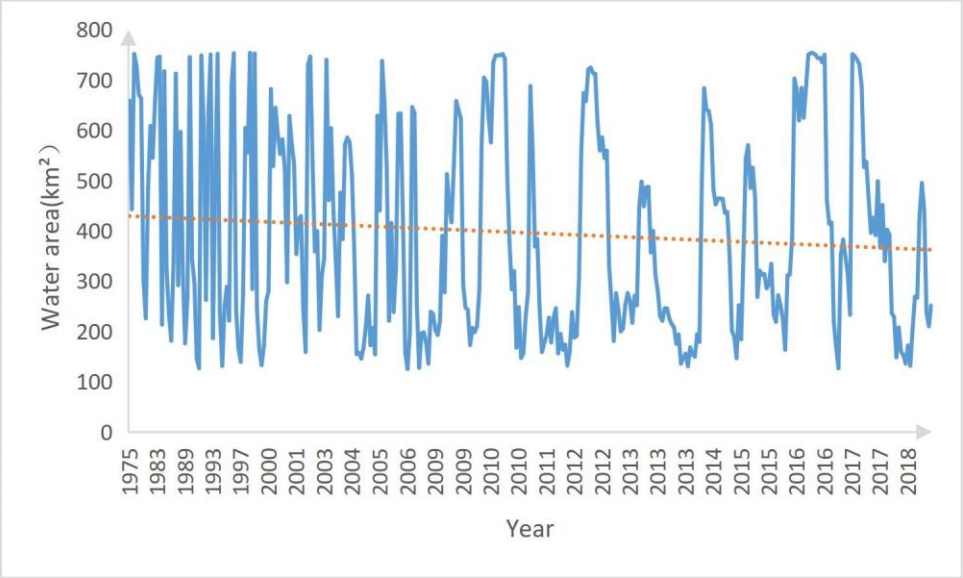

Figure 3. Annual area curve of dish-shaped.

The results show that the area of the dish-shaped Lake varies sharply between months, but not annually. On the whole, the water area change of Saucer Lake area shows a downward trend in the past 40 years. According to the results of spatiotemporal dynamic changes, the impact of Poyang Lake on the saucer lake ecosystem is mainly in the wet season. At this time, the water level of Poyang lake rises and the area expands.,which brought the whole dish lake into consideration.In the dry season, the water level of Poyang Lake drops and the area decreases, making the dish Lake independent of the main lake area, only affected by evaporation, rainfall infiltration and human activities, and less affected by the main lake area.

3.2. Influence Factor

3.2.1. Natural factor

Based on rainfall and evaporation data to analyze the water gain and loss map of Poyang Lake region.

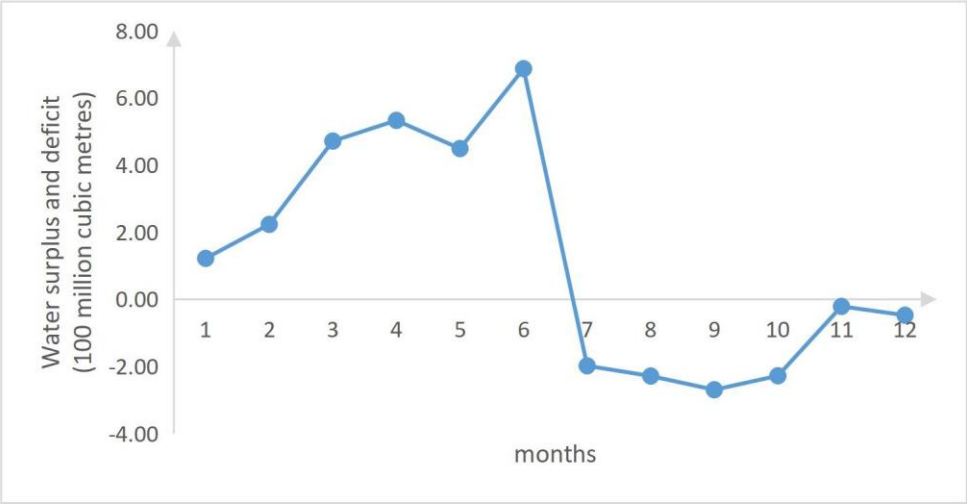

Figure 4. Regional Water profit-loss curve in Poyang Lake.

According to figure 4, affected by climate factors, the water volume of Poyang Lake area increased in the first half of the year, and decreased in the second half of the year. The maximum surplus appeared in June, which was basically the same as the area change trend of dish shaped lake area. In July, the evaporation was greater than the rainfall, but the dish-shaped Lake area reached the maximum water area. The reason is that the five rivers and the Yangtze River reached the high water level during the period of April to June. As a water storage lake, Poyang Lake received more water, so its area increased and the area of the dish lake was further expanded.

Therefore, when the saucer lake is connected with Poyang Lake, the water area is also affected by the inflow of Poyang Lake.

3.2.2. Human factor

It can be seen from Figure 5, in January, the water level of the saucer lake and the main lake area began to rise slowly. From February to may, the area of the main lake area of Poyang Lake increased rapidly, while that of the dish-shaped Lake increased slowly. After May, both the main lake area and the dish-shaped Lake area of Poyang Lake increased rapidly, reaching the maximum in July. After July, the dish-shaped Lake area fluctuated and decreased with the decrease of the main lake area; after September, both the main lake area and the saucer Lake area of Poyang Lake decreased rapidly.

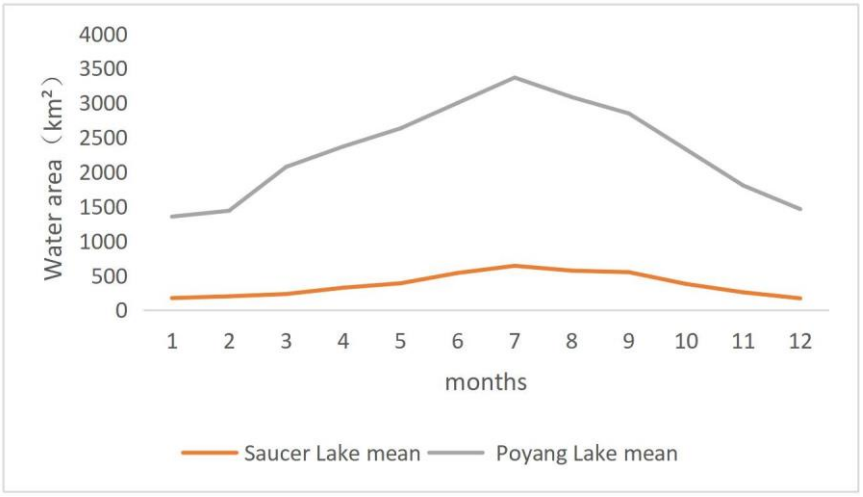

Figure 5. Comparison of changes in water area between Lake saucer and Poyang Lake.

The main human factor in the dish-shaped Lake area is the "chopping Lake" fishing operation. From February to may, the water area of Poyang Lake increased rapidly. At this time, the saucer lake

was independent of the main lake area, so the water area of the dish Lake changed little. After May, the water area of the dish lake and the Poyang Lake showed an increasing trend until the peak value was reached in July. From July to September, the water area of Poyang Lake decreased a lot, but the dish-shaped lake was relatively stable. During this period, the dish-shaped lake was separated from the main lake area again, until about October, The water area of Saucer Lake decreased rapidly after "cutting the lake" for releasing water.

Therefore, human activities have intensified the water level changes of the saucer lake, which makes the hydrological characteristics of the saucer lake and the main lake area of Poyang Lake near the dike are obviously different. This fishing method of "cutting off the autumn lake" blocks the hydrological connection between the dish lake and the outside world, and alleviates the impact of the main lake drought on the dish lake to a certain extent.

3.3. Impact of water area change on ecology

3.3.1. Impact on wetland vegetation

Saucer lake is basically in the range of wetland, which has an impact on the growth and distribution of wetland organisms in the region [18], resulting in the dynamic change of wetland types. From March to may, there is less rainfall in the region, and the water level of dish-shaped lake is relatively stable, maintaining the characteristics of shallow lakes,which provides superior environmental conditions for the development of wetland ecosystem. From June to September, the saucer Lake area is connected with the main lake area,the water area is larger and the lake is the main body; aquatic vegetation is developed in the wetland, and artificial water releasing fishing is carried out in the dish lake around October, the water level drops, the water area gradually decreases, the dish Lake separates from the main lake area, and the wet vegetation appears. During the period from December to February of the following year, part of the saucer Lake dried up. At this time, the lake bottom was exposed to the sun, and the remains of aquatic plants were completely decomposed, thus avoiding the swamping of the saucer lake and protecting the wetland ecosystem of the dish lake.

The difference of different submergence duration determines the gradient distribution pattern of vegetation zone. Therefore, the wetland and aquatic plant communities in the dish-shaped lake beach wetland are distributed in a ring and in a seasonal succession [19]. The seasonal and periodic water area change of Saucer lake also provides a good habitat adjustment environment for the succession of vegetation communities and aquatic organisms on the beach [20].

3.3.2. Impact on the number of migratory birds

The wintering habitat of waterfowl is generally broad shallow water area and wide mudflat swamp zone. The dish-shaped Lake area provides abundant food and suitable habitat for wintering migratory birds. It is the main area for wintering migratory birds to live and forage. More than 80% of the water birds in the lake overwinter in the dish-shaped Lake area, which is of great significance to the ecological regulation and control of Poyang Lake area [21].

In October every year, the water area of Saucer Lake gradually decreases, exposing the beach and the bottom of the lake, forming a new mudflat and water land alternate zone, providing wintering migratory birds with feeding and good habitat under shallow water level conditions. At this time, water birds begin to come to Poyang Lake, and the number increases steadily. In December, the number of migratory birds reaches the peak. From October to December, there was a negative correlation between them. When the water area of the dish-shaped Lake continued to decrease to the minimum in January, some of the saucer lakes even dried up, and the reduction of aquatic vegetation and plankton led to the reduction of effective foraging range of water birds. Wintering migrants move to other areas. In February, the rainfall increased relatively, and the dish-shaped lake, which had exposed the mudflat at the bottom of the lake, began to accumulate water. Plant residues and insect eggs in the lake began to recover and sprout, which provided a good habitat and foraging place for migratory birds and attracted a large number of migratory birds to return. After March, the climate became warmer, and wintering migratory birds moved to other areas in succession [22-23]. At this

time, the water volume in th Saucer Lake area began to increase obviously, the water area expanded and the beaches decreased, which affected the development of the surrounding vegetation and further affected the number of wintering migratory birds. Therefore, the change of water area in Saucer Lake area is a key factor affecting the species and quantity of wintering migratory birds.

4. Discussion

The change of dished Lake area is affected by many factors such as rainfall, evaporation, water coming from five rivers and human activities. The rainfall in the saucer Lake area and the whole Poyang Lake Basin is mainly from March to June. At this time, the rainfall greatly exceeds the evaporation. As shown in Figure 2, the water area of the dished Lake increases gradually from March to June. The impact of the inflow of the five rivers was mainly in July. Due to the excessive growth of the water volume of the five rivers in the summer news, it continued to flow into the Poyang Lake. The growth of the area of the Poyang Lake led to the synchronous growth of the area of the dished lake. As shown in Figure 2, the water area of the dished Lake further increased. The impact of human activities is mainly manifested in September to October, which is the fishing period of "cutting the lake". The water area of the dish lake is rapidly reduced as shown in Figure 2.

From the perspective of monthly average water area, Dished Lake showed an increasing trend from January to July, and a downward trend from July to December. From January to May and October to December, the saucer lake belongs to an independent lake, which is not connected with the main lake area, is not affected by five rivers and the main lake area, and has less human influence. It is mainly affected by rainfall and evaporation. From January to may, rainfall is greater than evaporation, and the area of dished lake continues to increase, while in October to December, evaporation is greater than rainfall, and the area of dished lake continues to decrease. From May to September, the saucer lake is connected with the main lake area. At this time, in addition to rainfall and evaporation, it is also affected by the water coming from the five rivers and the change of water volume in the main lake area. Among them, the rainfall from May to June is greater than the evaporation, and there is water from the five rivers, so the water area of the dish lake and the main lake area increases simultaneously; although the rainfall is less than the evaporation from June to July, the water area of the dish lake and the main lake area still increases synchronously due to the water from the five rivers.From July to September, the rainfall less than evaporation continued to increase, and the saucer Lake decreased with the reduction of the main lake area.On the whole, human activities have a significant impact on the water area of the dish lake, which is reflected in Figure 2. The largest change of the water area of the dish lake is from September to October. In terms of the annual average water area, the highest water level of Dished lake has gradually increased, mainly due to the joint influence of less precipitation in dry years and the decrease of water replenishment from the five rivers. However, the interference of human activities on the dish lake is also constantly strengthened, mainly in the aspects of water conservancy construction and fishery. Therefore, it is necessary to strengthen ecological protection and control the influence of human factors. Since the "chopping Lake" and the wintering of migratory birds are basically at the same time, it is suggested that the fishing time for releasing water should be adjusted scientifically to avoid the influence on the wintering of migratory birds. At the same time, the dished lake should be exposed to the sun in winter to avoid wetland swamping. After that, the research direction is the relationship between water level change and water area of saucer lake, combined with wetland ecosystem, to further understand the ecological impact of saucer lake on surrounding areas.

Acknowledgments: This research was financially supported by National Key Research and Development Program of China (2018YFC1506500), National Natural Science Foundation of China (41971402) and Open research fund of Hubei provincial key laboratory of regional development and environmental response (2018B(003)).

Author Contributions: The authors undertook different tasks for this paper. Hai Liu designed the research and provided direction to the research work. Shimian Wang and Zeyu An analyzed the data. Min Wang and Liang Zheng wrote and revised the paper. All authors have read and approved the final manuscript.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the

study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Lei,X.M.;Duan,H.L.;Liu,W.F.;Ji,Y.H.;Zhou,J.H.;Wu, J.P.; Fan, H.B. Soil Nutrients and Stoichiometry Along Elevation Gradients in Shallow-lakes of Poyang Lake Wetland.Soils,2017;49,40-48,DOI:10.13448/j.cnki.jalre.2017;116.
2. Sun,F.D.;Ma,R.H.Hydrologic changes of Poyang Lake based on radar altimeter and optical sensor. Acta geographica sinica,2020;75,544-557, DOI :10.11821/dlxb202003008.
3. Ji, W.T.; Ge,G.Butterfly lake,Chapter 2 Terrain of Poyang Lake,Li, H.H; Zhan, Y.H. The Science press.Beijing, China,2017;49-50.
4. Wu, Y.H.; Ji, W.T.; China Forestry Press. Beijing,China,2002;65-67.
5. Li, H.H. Changes of Water Level in Main Lake Area of Poyang Lake and in Dish-shaped Sub-lake and Their Impacts on Water Quality. Resources and Environment in the Yangtze Basin,2018;6,1298-1305. DOI : 10.11870 /cjlyzyyhj201806013.
6. Zhu,L.;Zhao,Y.W.;Liu,L.M.Protective Utilization and Function Estimate of Wetlands Ecosystem in Poyang Lake. Journal of Soil and Water Conservation,2004;18, 196-200, DOI : 10.13870/j.cnki.stbcxb.2004.02.050.
7. Chen,L.G.;Chen,L.M.; Jia,J.W.;Xu,Y.F.; Luan,Z.Y.; Shi,Y.Quantitative effects of water level variation on the habitat area of wintering waterfowl in dry season of the Poyang Lake. Journal of Hydraulic Engineering, 2019;50,1502-1508, DOI : 10.13243/j.cnki.slxb.20190647.
8. Li,H.; Li, C.A.; Zhang, L.H.; Tian, L.J. Relationship between water leveland water area in poyang lake based on modis image. quaternary sciences ,2008;28,332-337, DOI : 10.3321/j.issn:1001-7410.2008.02.016
9. Min, Q.; Zhan, N.S. Characteristics of low—water level changes in Lake Poyang during 1952—2011. Journal of Lake Sciences ,2012;24,675-678, DOI : 10.18307/2012.0505
10. Zhang, P.; Lu, J.Z.; Chen, X.L.; Tian, L.Q. Hydrodynamic Simulation of Water Extend Change in Poyang Lake with Aid of MODIS Remote Sensing Data. Geomatics and Information Science of Wuhan University ,2012;37,1087-1091, DOI : 10.13203/j.whugis2012.09.021
11. Zhan, F.P.; Fang, S.W.; Zhou, Z.H.; Wen, T.F.; Zhang, M.H. Research on multi-time-scale dynamic characteristics of water-level fluctuation of the poyang lake in china.Resources and Environment in the Yangtze Basin,2017;26,126-133, DOI : 10.11870/cjlyzyyhj201701015
12. Chen, L.G.; Chen, L.M.; Jia, J.W.; Xu, Y.F.; Luan, Z.Y.; Shi, Y.Quantitative influence of water level changes in Poyang Lake on the habitat area of wintering waterbirds in dry season[J]. Journal of Hydraulic Engineering, 2019; 50(12),1502-1509. DOI:10.13243/j.cnki.slxb.20190647
13. Wang, D.; Wang, D.; Qi, S.H. Analysis of the uncertainty of the relationship between Poyang Lake water level and flooded area[J]. Resources and Environment in the Yangtze Basin, 2016;25(S1),95-102.
14. Liu, J.Y.; Zhang, Q.; Deng, X.Y.; Ci, H.; Chen, X.H.Quantitative analysis of the impact of climate change and human activities on the runoff process in Poyang Lake Basin[J]. Lake Science, 2016;28(02),432-443. DOI:10.18307/2016.0224
15. Rao, D.D.;Yu, X.B.;Li, P.;Xia, S.X.;Meng, Z.J.;Liu, Y.Remote Sensing Estimation of Carex Biomass in the Disc-shaped Lake (Changhuchi) of Poyang Lake [J]. Journal of Natural Resources, 2019;34(09),2001-2011. DOI:10.31497/zrzyxb.20190915
16. Wu, G.P.; Liu, Y.B.; Zhao, X.S.; Ye, C. Spatio-temporal variations of evapotranspiration in Poyang Lake Basin using MOD16 products. Geographical Research ,2013;32,617-627,
17. Song, X.M.; Zhang, J.Y.; Zhan, C.S.; Liu, C.Z.; Review for impacts of climate change and human activities on water cycle. Journal of Hydraulic Engineering, 2013;7,779-790. DOI :10.13243/j.cnki.slxb.2013.07.001
18. Wantzen, K.M.; Rothhaupt, K.O.; Mrtl, M. Ecological effects of water-level fluctuations in lakes.an urgent issue. Hydra biologia,2008;613,1-4.
19. Ge, G.; Ji, W.T.; Liu, C.L.; Xiong, S.; Wu, Z.Q. Hydraulic project and wetland ecological protection in poyang lake. resources and environment in the yangtze basin ,2010;19,606-613.
20. Li, R.D.; Liu, J.Y. An Estimation of Wetland Vegetation Biomass in the Poyang Lake Using Landsat ETM Data. acta geographica sinica ,2001;56,532-540. 10.3321/j.issn:0375-5444.2001.05.004
21. Qi, S.H.; Liu, Y.; Yu, X.B. Effect of"lake enclosed in autumn"on the habitat of winter bird in poyang lake. Resources and Environment in the Yangtza Basin ,2011;1,18-21.

22. Hu, Z.P.; Ge, G.; Liu, C.L. Response of Wintering Migratory Birds to Hydrological Processes in Poyang Lake. Journal of Natural Resources ,2014;29,1770-1779, DOI :10.11849/zrzyxb.2014.10.012
23. Guo, H.C.; Hu, B.H.; Li, Q. Effects of autumn fishery by enclosing plate-shaped lake on the winter migratory birds and conservation strategies in nanji wetland national natural reserve of the poyang lake,jiangxi. Resources and Environment in the Yangtze Basin,2014;23,46-52, DOI : 10.11870/cjlyzyyhj201401007.
24. Cheng, L.; Xu, Z.X.; Zuo, D.P. Identification of water bodies in the loess plateau based on landsat tm dataset. journal of beijing normal university (natural science), 2010;46,424-430.
25. Mcfeeters, S.K.The use of Normalized Difference Water Index (NDWI) in the delineation of open water features[J]. International Journal of Remote Sensing ,1996;17,1425-1432.